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PC Software Graphics Tool for Conceptual Design of Space/Planetary Electrical Power Systems

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PC SOFTWARE GRAPHICS TOOL FOR CONCEPTUAL DESIGN OF SPACE/PLANETARY ELECTRICAL POWER SYSTEMS

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ABSTRACT

This paper describes the Decision Support System (DSS), a personal computer software graphics tool for designing conceptual space and/or planetary electrical power systems. By using the DSS, users can obtain desirable system design and operating parameters, such as system weight, electrical distribution efficiency, and bus power. With this tool, a large-scale specific power system was designed *in a matter of days*. It is an excellent tool to help designers make tradeoffs between system components, hardware architectures, and operation parameters in the early stages of the design cycle.

The DSS is a user-friendly, menu-driven tool with online help and a custom graphical user interface. An example design and results are illustrated for a typical space power system with multiple types of power sources, frequencies, energy storage systems, and loads.

INTRODUCTION

The conceptual design of space and/or planetary electrical power systems, such as for the former space station, Freedom, has required considerable effort. Traditionally, in the early stages of the design cycle (conceptual design), researchers had to thoroughly study and analyze tradeoffs between system components, hardware architectures, and operation parameters, such as frequencies, for their effect on system mass, efficiency, reliability, and cost. This process could take anywhere from several months to several years (as for the former Space Station Freedom), depending on the scale of the system.

Although there are many sophisticated software design tools for personal computers (PC's) in the commercial market, none of them can support or provide a total system design (system weight, electrical distribution efficiency, and bus power). To meet this need, we are developing a new tool to help project managers and design engineers choose the best system parameters as quickly as possible in the early design stages (in days instead of months). This new tool is called the Decision Support System (DSS).

This paper introduces the DSS tool at its present stage of development and presents a typical conceptual design for a space electrical power system with multiple types of power sources, frequencies, energy storage systems, and loads.

BRIEF DESCRIPTION OF THE DSS SOFTWARE STRUCTURE

Figure 1 shows a simplified block diagram of the DSS software structure. It describes the integration of the software modules (ovals) and the flow of information (rectangles) throughout the system. The DSS provides access to the analysis tools required through a custom graphical user interface and common data bases. It operates on any IBM/AT (International Business Machines, Inc.) or compatible personal computer (PC) with an MS–DOS (Microsoft Corporation) operating system, version 5.0 or later. A color monitor (EGA or VGA) and a two-button mouse are required. A virtually unlimited (limited only by the size of the hard drive) number of hardware diagrams can be created, logically wired, and then dynamically recalled for display and analysis in real time with mouse commands.

In the next section, an example is given to illustrate some of the DSS features. Detailed descriptions of the DSS calculation techniques, formulas, and reference data bases are given in Kusic and Cull (1994), Space Station Systems Engineering and Integration (1992), Metcalf (1992), and NASA Parts Project Office (1992).

DESIGN EXAMPLE

The following example was designed and executed on a 25–MHz 486DX PC with a math coprocessor. Its design topology, data input, and output results are described in the following sections. Because of space limitations, most usage instructions—such as those for installing the software, using the run-time graphics routine, and linking data for superimposing onto graphics frames—are not included here, but can be obtained by contacting the author.

Design Topology

This example represents a system for a space station. It assumes that all electrical loads will be supplied by two parallel power modules working as a system (up to 10 power modules can run in parallel for reliability): (1) a 150-Vdc photovoltaic system using nickel-hydrogen (NiH_2) batteries for energy storage and (2) a 400-Vac, 2-kHz solar dynamic system using a salt reservoir for energy storage. Power module #2 serves as a secondary power source for power module #1 through the distribution ties. The system is designed for a low-Earth orbit mission at an altitude of about 350 km.

Data Input

The following paragraphs describe typical procedures for entering data. In addition, users can access help instructions for user interface commands by clicking (pressing and releasing) the right mouse button.

Starting the DSS Tool. From the DOS prompt, change (CD) to the DSS directory, type DSS, and press the `Enter` key.

Entering Graphics Data and Drawing Hardware Diagrams. By pressing the `F` key (the frame maker key) at any time, users can access the system graphics utility. This utility allows users to create and link all the system hardware diagrams. Most of the creation and linking processes are guided by online instructions.

For this example, Figure 2 shows a typical top-level hardware diagram of power module #1, Figure 3 shows a diagram of power module #2, and Figure 4 shows a sublevel diagram of load area #4 (see Fig. 2). Because of space limitations, most of the component hardware sublevel diagrams are not presented here.

Entering Numerical Data. By selecting the appropriate menu options, users can enter numerical data via the keyboard. In addition, online instructions guide users throughout the input process. Six different types of data bases are available for saving data. They are system topology, power source, transmission cable, load converter, special load, and equipment data bases.

The numerical data assumed for the system topology, power source, equipment, transmission cable, load converter, and special load input are given in Tables I to VI, respectively.

Output Results

It takes about 2 days to input both the numerical and graphical data for this typical design example (section III). The run-time process to output the results is *only* about 25 seconds. Figures 5

TABLE I.—SYSTEM TOPOLOGY INPUT

Orbit altitude, km	350
Number of power modules in the system	2
Load power redundancy, 0 to 100 percent	100
Generation tie option presented to module #1, Y or N	N
Distribution tie option presented to module #1, Y or N	Y
Duration of peak load with respect to orbit cycle, 0 to 100	50
Power flows in generation tie to module #1, ±kW	0
Power flows in distribution tie to module #1, ±kW	-20

TABLE II.—POWER SOURCE INPUT

Data descriptions	Power module #1	Power module #2
Reduced load power during eclipse, kW	25	10
Peak power from total sources, kW	50	30
Total solar dynamic power, percent	0	100
Total photovoltaic power, percent	100	0
Total thermodynamic power, percent	0	0
Number of batteries	4	1
Buck/boost capacity for charge/discharge units	Y	Y
Power capacity of charge/discharge units, W	8298	1000
Storage energy supplied by NiCd, percent	100	100
Storage energy supplied by NiH_2, percent	0	0
Depth of discharge, 0 to 100 percent	40	40
Redundancy, 100/N to 100 percent	50	40
Generation bus tie option, Y or N	N	N
Distribution bus tie option, Y or N	Y	Y
Generation bus voltage, Vrms	150	440
Generation bus frequency, 0 to 20 000 Hz	0	2000
Power factor for ac system, default = 0.8	1	0.8
Tapper charge option, Y or N	N	Y
Node/bus number of battery #1	9	35
Node/bus number of battery #2	12	–
Node/bus number of battery #3	15	–
Node/bus number of battery #4	18	–

TABLE III.—EQUIPMENT INPUT

From node	To node	Type[a]	Ω or W	Calculated node
Power module #1				
2	3	2	0.012000	31
4	5	1	.000002	0
7	8	2	.100000	9
10	11		.100000	12
13	14		.100000	15
16	17		.100000	18
19	20	1	.005000	0
29	30	1	.000000	0
Power module #2				
36	37	1	0.100000	36
33	34	1	.100000	33
39	40	1	.100000	41

[a]Type 1 is resistance loss. Type 2 is equipment loss.

TABLE IV.—TRANSMISSION CABLE INPUT

From node	To node	Length, ft	Size, AWG	Number of RBI[a]
Power module #1				
31	2	0	-3	0
3	4	42.85	-1	0
5	6	5.00	-1	1
6	7	8.00	4	0
8	9	13.00	4	0
6	10	28.40	4	1
11	12	13.00	0	0
6	13	27.40	4	1
14	15	13.00	4	0
6	16	0	0	1
17	18	0	0	0
6	19	219.00	-1	1
20	21	200.00	-1	
21	22	95.60	4	
21	23	100.70	2	
21	24	93.50	4	
21	25	76.70		
21	26	67.00		
21	27	73.35		
21	28	87.40		
06	29	27.40		
01	21	0	-3	
Power module #2				
32	42	30.30	-1	1
38	42	40.00	-2	
32	37	20.00	0	
32	36	18.00		
32	33	10.00		
34	35	8.75		
32	39	10.00	2	
32	41	30.00	0	2

[a]Remote bus isolater.

to 7, respectively, show output samples for the system bus power, load cycle analysis, and top-level system report. Again, because of space limitations, other details are not presented here.

FUTURE WORK

At the present time, only the system mass, efficiency, and bus power can be analyzed. System reliability and cost are our next targets. We plan to use a method called the Combined Analysis of Reliability, Redundancy, and Cost (CARRAC) (Suich and Patterson, 1993), which was developed at the NASA Lewis Research Center. By using the CARRAC method, we will be able to select a power subsystem that minimizes the total expected cost of a spacecraft or planetary system. We are interested in exchanging technical feedback and ideas with volunteer users and researchers that share our interest in this research area.

CONCLUSIONS

The Decision Support System (DSS) is a user-friendly, menu-driven tool with online help and a custom graphical interface. The DSS is an excellent tool to help project managers and design engineers make tradeoffs between system components, hardware architectures, and operational frequencies in the early stages of the design cycle.

ACKNOWLEDGMENTS

The author thanks the project manager, Ronald Cull, for his advice and support, and George Kusic for his contribution of the load-flow analysis software routine.

TABLE V.—LOAD CONVERTER INPUT

Cable length, ft	Terminal 1 voltage, V	Terminal 2 voltage, V	Terminal 1 nominal power, W	Terminal 2 nominal power, W	Terminal 1 rated power, W	Terminal 2 rated power, W	Type[a]	From bus or converter	Fre-quency, Hz	Resis-tance, Ω	Bus
Power module #1											
0	150.0	0	6000.0	0	6250.0	0	0	10024	1	0.0000	0
15.0	5.0		20.0		20.0		1	1		.0265	
10.0	120.0		2000.0		2000.0		0	1		.0130	
12.0	28.0		3980.0		3980.0		1	1		.0065	
0	15.0		1500.0		6250.0		0	10025		0	
15.0	15.0		500.0		500.0		1	5	0	.0065	
18.0	15.0		500.0		500.0		1	5	0	.0065	
22.0	15.0		500.0		500.0		1	5	0	.0065	
0	5.0	-5.0	150.0	150.0	150.0	150.0	0	10025	1	0	
20.0	5.0	28.0	10.0	28.0	200.0	28.0	2	10025		.0268	
0	120.0	0	6200.0	0	6250.0	0	0	10023		.0000	
20.0			650.0		6000.0		1	10026		.0065	
20.0			5400.0		6000.0		1	10027		.0065	
20.0			2400.0		6000.0		1	10028		.0130	
0	200.0		5250.0		5250.0		0	16		.0000	
10.0	2000.0		5500.0		5500.0		1	17	1000	.0130	
10.0	440.0		6000.0		6250.0		1	10029	20000	.0065	
Power module #2											
0	150.0	0	6000.0	0	6000.0	0	1	10038	1	0.0065	10001
90.0	440.0		5000.0		5000.0		1	10036	1	.0040	0
0	150.0		8000.0		8000.0		0	10041	1	.0130	10001
90.0	208.0		5000.0		5000.0		1	10032	400	.0130	0

[a]Type 0 has a dummy converter (not used in calculations—see dashed boxes in Figure 4). Type 1 has a dc converter. Type 2 has an ac converter.

TABLE VI.—SPECIAL LOAD INPUT

Power module	Number of loads	Resistance	Node
#1	1	0.001	22
#2	1	0.001	32

REFERENCES

Kusic, G. L., and Cull, R. C., 1994, "A Power System Design Tool for Aerospace Applications," Twenty-ninth Intersociety Energy Conversion Engineering Conference, Monterey, California, Aug. 7–11, pp. 619–624.

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Suich, R. C., and Patterson, R. L., 1993, "Minimize System Cost by Choosing Optimal Subsystem Reliability and Redundancy," NASA TM–106251.

Truong, L. V., 1993, "Living Color Frame System: PC Graphics Tool for Data Visualization," Conference on Intelligent Computer-Aided Training and Virtual Environments Technology, Houston, Texas, May 5–7.

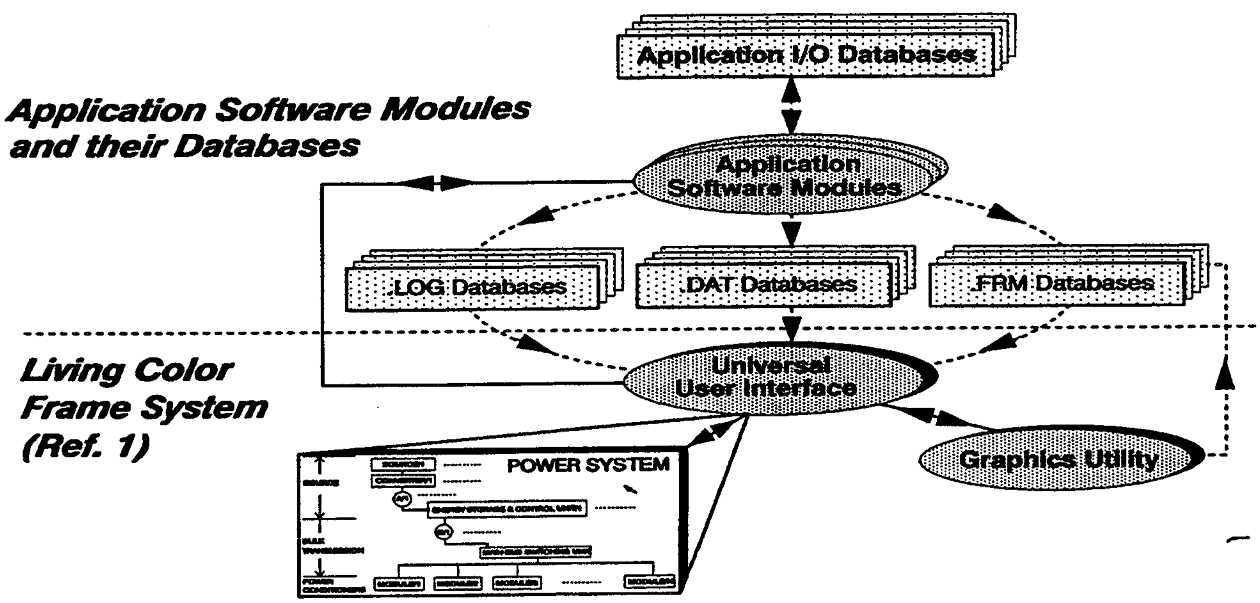


FIGURE 1.—SIMPLIFIED DSS SOFTWARE STRUCTURE (TRUONG, 1993).

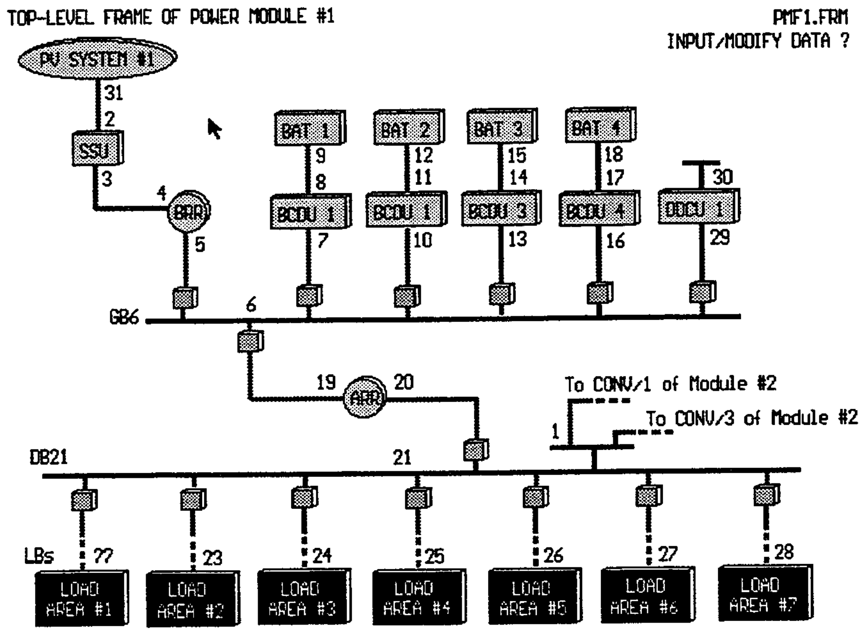


FIGURE 2.—TOP-LEVEL DIAGRAM OF POWER MODULE #1.

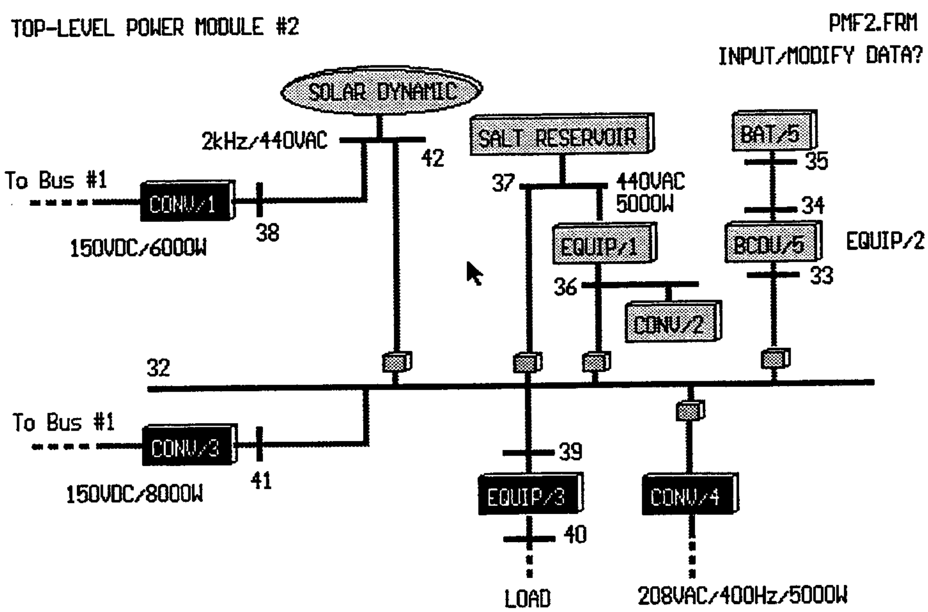


FIGURE 3.—TOP-LEVEL DIAGRAM OF POWER MODULE #2.

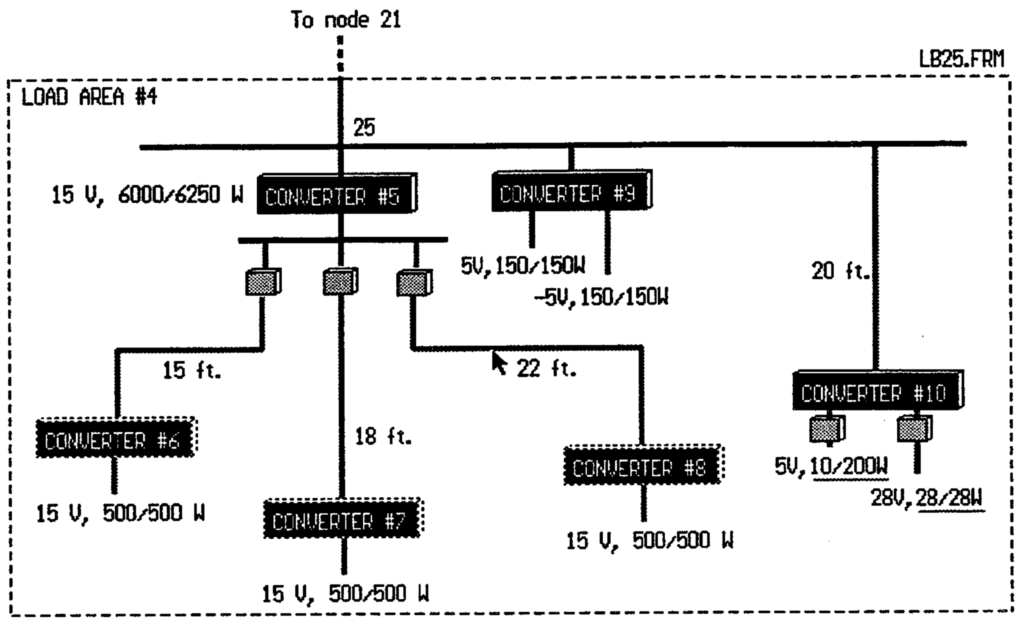
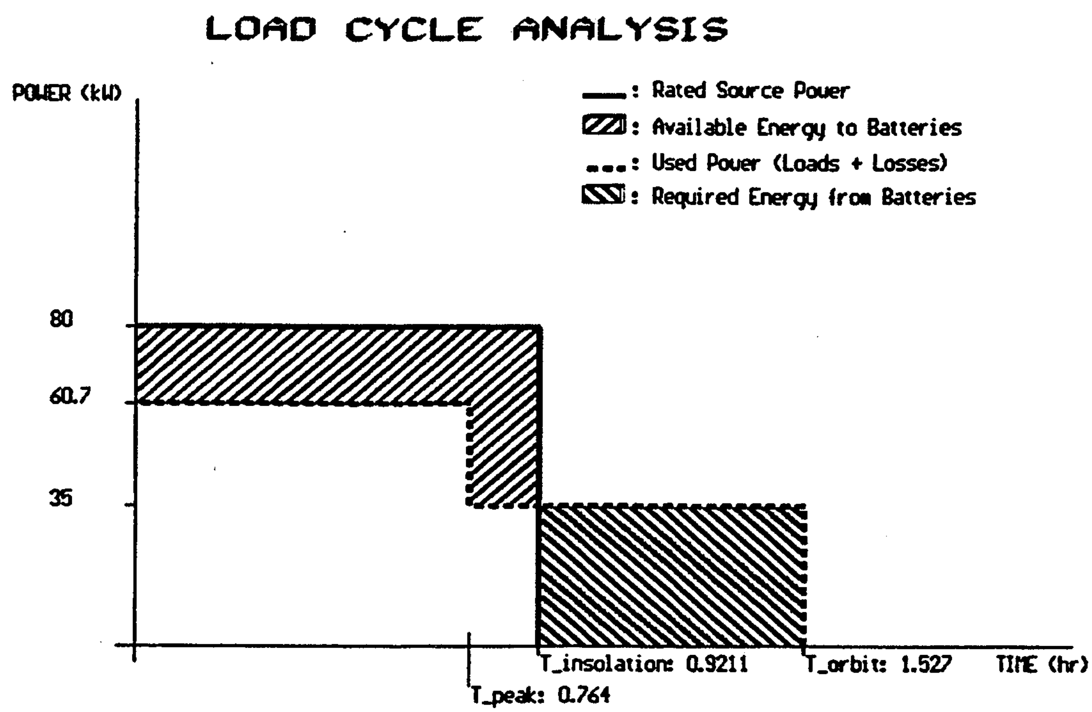


FIGURE 4.—SUBLEVEL DIAGRAM OF LOAD AREA #4 (FIG. 2).

```
...
Load is supplied by  2  modules
T_orbit, eclipse, insolation (Hrs) = 1.527, .605, .921
Txra =   1.575794E-01
Load interval time T1, T2, T3 Hrs. = .76, .16, .61

TIME PERIOD =  1 (INSOLATION)
    Module number  1  Source rating =    50.0 kW
    Eclipse time converter kW load  =    25.00
    Number of converters =    17
    Power, kW, =      7.236 Bus =      24
    Power, kW, =      2.253 Bus =      25
    Power, kW, =      6.757 Bus =      23
    Power, kW, =      5.092 Bus =      26
    Power, kW, =      5.903 Bus =      27
    Power, kW, =      2.660 Bus =      28
    Power, kW, =      6.506 Bus =      29
    Peak Converter load = 32.488000 kW
    Bus load due to converters = 36.407110 kW
    ....
    Module number  2  Source rating =    30.0 kW
    Eclipse time converter kW load  =    10.00
    Line conv., a,buses= 6.291, -6.000, 38, 1
    Line conv., a,buses= 8.365, -14.000, 41, 1
    Number of converters =    4
    Power, kW, =      6.293    Bus =     38
    Power, kW, =      5.255    Bus =     36
    Power, kW, =      8.370    Bus =     41
    Power, kW, =      5.490    Bus =     32
    Peak Converter load = 24.000000 kW
    Bus load due to converters = 25.400580 kW
    ....
....
```

FIGURE 5.—TYPICAL LIST (PARTIAL) OF BUS POWER OUTPUT.



> Load Cycle Storage Energy Balance: 0.589 kW-hr

FIGURE 6.-GRAPHICAL DISPLAY OF LOAD CYCLE ANALYSIS.

```
******************************** SYSTEM RESULTS ******************************
                     weights    insolation        overlap          eclipse
                    KILOGRAMS  EFFICIENCY (%)   EFFICIENCY (%)   EFFICIENCY (%)
MODULE 1 RESULTS:
SOURCE               536.
SSU                   28.        98.845
BATTERIES           1919.        95.500              .000           84.300
BCDU s               553.        91.216              .000           92.000
TRANS NETWORK        328.        96.098            97.797           98.048
RBI s                272.
DISTR NETWORK          4.       100.000           100.000          100.000
RPC s                 21.
ALL CONVERTERS       889.        89.235            88.559           88.559
RADIATORS            110.
TOTAL MOD WT(kg)    4661.
SOURCE RATED ENERGY= 46.06 kW-Hrs, used = 35.94 kW-Hrs.   Battery DOD % =21.8
TRANSMISSION LOSSES=  2.18 kW-Hrs= 1.73 plus        .10 plus          .36
BCDU LOSSES=          2.06 kW-Hrs= 1.29 plus        .02 plus          .75
BATTERY LOSSES=       2.44 kW-Hrs=  .69 plus        .00 plus         1.75
CONVERTER LOSSES=     6.39 kW-Hrs= 3.51 plus        .59 plus         2.28
SWITCHGEAR LOSSES=     .08 kW-Hrs=  .05 plus        .01 plus          .02
MODULE 2 RESULTS:
SOURCE              2729.
SALT RESERVOIR       212.
BATTERIES            115.        95.500            95.500           84.300
BCDU s                23.        92.000            91.485           92.000
TRANS NETWORK         70.        95.250            98.204           97.300
RBI s                163.
DISTR NETWORK          4.       100.000           100.000          100.000
RPC s                  3.
ALL CONVERTERS       118.        94.486            94.547           94.547
RADIATORS            231.
TOTAL MOD WT(kg)    3667.
SOURCE RATED ENERGY= 31.59 kW-Hrs, used = 31.59 kW-Hrs.   Battery DOD % =  .0
TRANSMISSION LOSSES=  1.12 kW-Hrs=  .79 plus        .05 plus          .28
BCDU LOSSES=          6.69 kW-Hrs= 6.64 plus        .01 plus          .04
BATTERY LOSSES=       4.00 kW-Hrs= 3.91 plus        .01 plus          .08
CONVERTER LOSSES=     1.87 kW-Hrs= 1.07 plus        .17 plus          .63
SWITCHGEAR LOSSES=     .01 kW-Hrs=  .01 plus        .00 plus          .00
******************************************************************************
...
```

FIGURE 7.—TYPICAL SYSTEM SUMMARY REPORT.

REPORT DOCUMENTATION PAGE

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13. ABSTRACT ***(Maximum 200 words)***

This paper describes the Decision Support System (DSS), a personal computer software graphics tool for designing conceptual space and/or planetary electrical power systems. By using the DSS, users can obtain desirable system design and operating parameters, such as system weight, electrical distribution efficiency, and bus power. With this tool, a large-scale specific power system was designed in a matter of days. It is an excellent tool to help designers make tradeoffs between system components, hardware architectures, and operation parameters in the early stages of the design cycle. The DSS is a user-friendly, menu-driven tool with online help and a custom graphical user interface. An example design and results are illustrated for a typical space power system with multiple types of power sources, frequencies, energy storage systems, and loads.

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